1-1-1977

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Reprinted from

Symposium on

Machine Processing of

Remotely Sensed Data

June 21 - 23, 1977

The Laboratory for Applications of
Remote Sensing

Purdue University
West Lafayette
Indiana

IEEE Catalog No.
77CH1218-7 MPRSD

ISURSL LEVELS CLASSIFICATION: A LOW COST APPROACH TO MULTISPECTRAL DATA ANALYSIS

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I. ABSTRACT

The Indiana State University Remote Sensing Laboratory (ISURSL) recognized that the promise of low-cost earth resource evaluation through machine-assisted processing of multispectral (MS) data has not been fully realized. In response to this problem the ISURSL has developed a complete low-cost system of processing MS data which minimizes analysis time for both man and computer while simultaneously maximizing utilization of the data. The basis of the ISURSL classification algorithm, designated LEVELS CLASSIFIER, is identification of numeric boundaries located in multidimensional feature space which differentiate features of interest. Land use classes of interest to an analyst are described by the range of radiance (relative spectral response) levels which define these boundaries. The identification of levels boundaries which accurately defines an earth surface feature is accomplished through sophisticated single and multidimensional histogram terrain analysis. This approach to multispectral data analysis has been shown to be cost effective and accurate in several applied research projects at ISURSL.

II. INTRODUCTION

The need for low-cost information acquired through computer-assisted processing of multispectral data is great. During the past two years the Indiana State University Remote Sensing Laboratory (ISURSL) has focused a large share of its activities toward developing a computer processing system which will provide low-cost land use and land cover information from satellite and aircraft multispectral data. Since 1974 ISURSL has had access to the facilities of the Laboratory for Application of Remote Sensing (LARS) at Purdue University through a remote computer terminal. It became apparent to the staff of ISURSL that applied research using the full capabilities of the traditional LARS software (LARSYS) is too costly for many potential users. This potential user community includes local, state, and regional planners, research and institutional centers and industry. This report is a summary of the current ISURSL low-cost computer processing system developed for analysis of remotely sensed data. The development of a low-cost processing system is also timely due to the impending "Thematic Mapper" of future LANDSAT satellites.

The authors of this paper have developed a set of algorithms which functionally parallels the traditional LARSYS approach to multispectral analysis but requires, by conservative estimates, one-third to one-fourth the cost to complete a classification study. The ISURSL developed algorithms were refined and adapted into the LARSYS system environment with the assistance of LARS personnel (Phil Alenduff, Paul Spencer and Bill Simmons).

The ISURSL classification approach is designated Levels Classification. The effectiveness of the ISURSL Levels Classification approach has been demonstrated in a number of basic and applied research projects and contracts. Evaluation of these initial results indicates that the accuracy of classification using the ISURSL approach is commensurate with more costly traditional supervised and unsupervised approaches. A Levels Classification analysis of a test site in Marion County, Indiana is presented in this paper to help demonstrate the system's functions and to illustrate the products generated by each processor (Figure 1).

III. THE LEVELS CLASSIFICATION SYSTEM STRUCTURE

Figure 2 identifies the processors which are used most frequently for multispectral data analysis in the traditional LARSYS system and the ISURSL Levels Classification environment. The parallel development of the ISURSL processors relative to established LARSYS processors is evident. The core of the ISURSL system is the classification algorithm, the Levels Classifier. The ancillary programs provide preliminary and

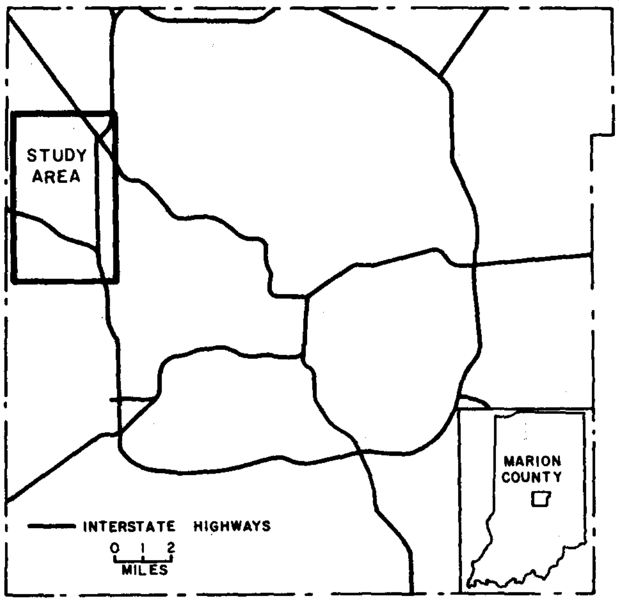

Figure 1. Marion County, Indiana Study Area

progressive information about the fundamental structure of the data set and the potential success of identifying the desired earth surface features within the data set. The cluster algorithm, BIRTHA, can be used independently as an unsupervised classifier. However, in general BIRTHA is used as an ancillary processor.

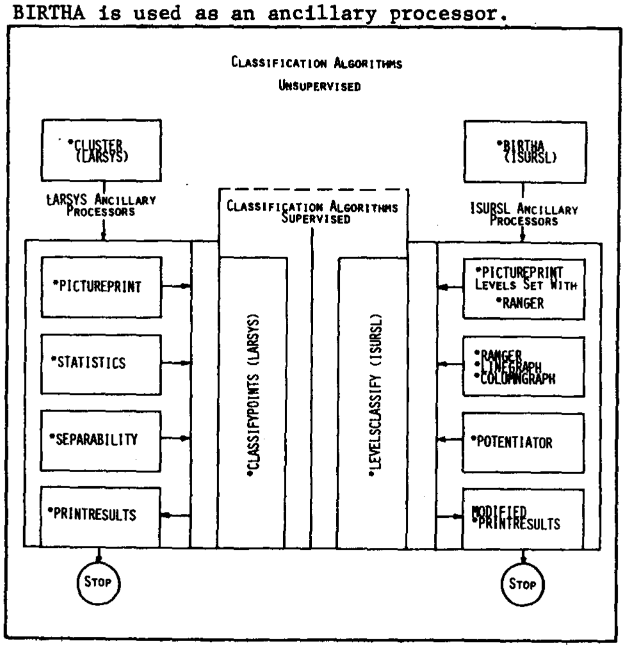

Figure 2. Comparison of LARSYS and ISURSL classification systems.

The flow chart, Figure 3, represents the operational structure of the ISURSL system from the point of view of the analyst. Data are acquired from various sources, such as EROS, ERIM, and NOAA. LARS reformats and geometrically corrects the data. The data then are available to the ISURSL staff through the remote terminal. The processors the analyst selects to use are dependent on the requirements of the study. At each stage of analysis the analyst decides which processors are needed to provide the desired results. The first decision is to select either the supervised or unsupervised mode. This choice depends on the complexity of the study and the anticipated effectiveness of the cluster algorithm in generating the classes of interest. Once the mode of analysis is selected the analyst processes the data and evaluates the results. The analyst returns to the first decision and continues iteratively to converge on the desired classification scheme if results are unsatisfactory. At various steps in the analysis both the supervised and unsupervised modes may be required to develop the classification scheme effectively. Once the desired classification scheme is generated, the analyst optimizes the classification time by selecting either the single channel or minimum number of channels needed to identify the desired classes.

IV. THE LEVELS CLASSIFIER

Levels Classification is a form of simultaneous multiband density slicing. The concept of classifying multispectral data through multidimensional density slicing is intuitively straight-forward. Variations of multiband

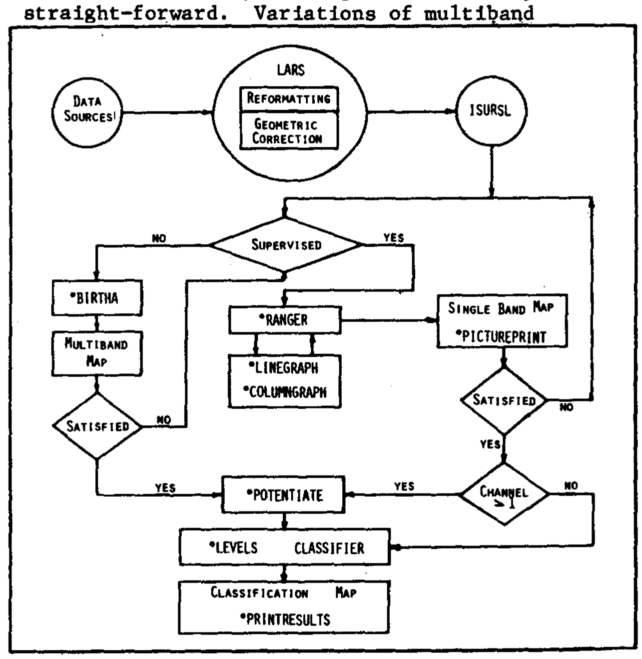

Figure 3. Flow Diagram of ISURSL Levels Classifier System

density slicing are used by the G.E. Image 100, the I^2S 101 and other image enhancement systems. Multiband density slicing also is used in the Eppler "Look-Up Table" Classifier and in other forms at remote sensing laboratories in Italy and Canada.[1] However, the fundamental precept of Levels Classification is unique to other techniques of multidimensional density slicing.

A. THE CONCEPT

In Levels Classification a class is identified successfully if the relative spectral response range (levels) in one channel or a combination of channels is unique to that class when compared to all other classes. The basic requirement is that at least one spectral band effectively discriminates between any two classes. Any given class may require more than one spectral band to isolate it from all other classes because the same spectral band may not separate all classes of interest. The channel or channels subset used for isolating each class is semi-independent of the channel or channels subset used to discriminate other classes. This concept is described analytically as:

given a data set with M features,

$F_{1,2,\ldots,m}$

with which to identify N classes,

$C_{1,2,\ldots,n}$

Each class is defined as a set in the feature space or subspace as c_i, where c_i is in the range $f_i - \Delta_i \leq c_i \leq f_i + \Delta_i$ and c_i, $i = 1,p;\ p \leq m$

A class $C_i^!$ is distinct in this feature space if set $c_i^!$,

$i = 1,p$ for i, $i = 1,m, C_i^! \, \Omega \, Ci = 0$ for all classes.

B. ADVANTAGES

A number of advantages are inherent in the Levels Classification approach. The primary advantage is a significant reduction in computer time needed to analyze multispectral data. This is because of the elimination of distance calculations needed to assign pixels to classes in traditional classifiers. It is possible to produce thematic maps quickly and at low cost by specifying only one class. Major classes in a study area, such as water, forest, agriculture, and urban may be examined and then each general class may be broken down into subclasses. For example, the class forest may be separated into subclasses, coniferous, deciduous and mixed forest by specifying subsets of the levels specified for the class forest. In addition, preliminary ISURSL research indicates that discrimination between certain classes which are relatively inseparable using traditional methods often can be attained with Levels Classification. There is also the possibility that two or more ranges in any spectral band are descriptive of a class of interest. Theoretically it is possible to specify all ranges in each band which are associated with a class.

V. CLASS BOUNDARY IDENTIFICATION

Simplicity is fundamental in Levels Classification. The numeric boundaries between classes are determined by the minimum and maximum radiance values typical of each land use or land cover category. It became evident early in the development of the ISURSL Levels Classification that identifying simple levels boundaries in multidimensional feature space was complex. This is due to the large number of possible levels range combinations in multidimensional feature space even for the four feature aspect of current LANDSAT data. These boundaries must be determined in some manner; however, the use of inferential statistical techniques for this purpose is too complex and expensive. Although the concept of identifying boundaries with descriptive statistics in multidimensional feature space is not well accepted, it was selected because of low cost and demonstrated effectiveness.

A. CONCEPT

The basic technique for boundary identification in ISURSL Levels Classification is feature separation through histogram terrain analysis. The fundamental concept is that a given earth surface feature will have a characteristic radiance. This characteristic radiance will be identified as a unimodal density distribution which has the form of a peak and two adjacent valleys in the histogram terrain. The range of radiance responses within this mode delimits the characteristic radiance of the earth surface feature. Since the morphology of the histogram is dependent on the data sample from which it is compiled, a number of progressive steps initially are required to study the basic structure of the data and converge on identifying the specific classes of interest. Histogram analysis is conducted both for single and multidemensional feature space.

B. ADVANTAGES

The primary advantage of histogram analysis for boundary identification is, as with the Levels Classifier, a significant reduction in the computer time required for analysis when compared with traditional inferential techniques. Further, the boundaries identified through histogram analysis are easily associated with the original data values, which generally is not the case with typical inferential techniques. This direct link between the boundary identification processors and the classification technique allows the analyst to optimize class boundaries in the data set in an interactive manner. The final decision to assign any radiance response in the data set to any given class is left to the analyst who has access to ancillary ground information.

VI. ISURSL LEVELS CLASSIFICATION SYSTEM PROCESSORS

The processors used in Levels Classification were either already available in the LARSYS system, or were designed by the ISURSL staff to work within the LARSYS environment, or in one case (BIRTHA) borrowed from another source, modified and made compatible with the Levels Classifier and the LARSYS environment. These processors provide information about the structure of the data in single and multidimensional feature space and thereby facilitate effective analysis of earth surface features using Levels Classification.

A. RANGER

Ranger is a multipurpose processor which is comprised of component features from a number of LARSYS and ISURSL experimental processors. Ranger provides histograms and tabular reports of the levels in selected data samples. Samples may be from large segments of the data set which results in providing the general data structure of a study area. Small training field-type samples may be used to investigate the data structure within specific classes of interest. The processor can provide histograms and ranges for each data sample or it can compile composite histograms and levels ranges from a number of samples which comprise a single class.

In order to optimize the graphic quality of the Ranger histograms a specially designed histogram processor, HISTOR, was developed at ISURSL (by Steven D. McCloud, consultant to ISURSL). This program allows the analyst to control the bin size of the histogram. The histogram prints down the length of as many line printer pages as is needed to display the maximum radiance resolution of the data. The graphic also is optimized to use full page width for the largest frequency in the histogram and hence accentuates the modal structure of the data.

Following a period of HISTOR type histogram analysis, certain exaggerations in the reflectance densities were noted in LANDSAT data. Portions of the terrain in LANDSAT bands 4, 5, and 6 are artifacts of the data preprocessing procedures performed at the Goddard Space Flight Center at Greenbelt Maryland. The authors conducted a detailed investigation which indicated that a data decompression procedure performed at Goddard was the source of these artifacts.[2] A smoothing routine which eliminates the artifact terrain in LANDSAT data has been implemented to enhance the utility of histograms of LANDSAT bands 4, 5, and 6. The ISURSL HISTOR function is an intregal part of the Ranger processor. Examples of the Ranger function are provided in Figures 4 and 5.

B. LINE AND COLUMN GRAPHS

The LARSYS *Linegraph/*Columngraph functions provide cross-profile views of the relative spectral response values for a specified line or column of data in all channels. Various patterns can be seen in the data profile and these patterns change as different land covers are traversed in the line or column graphs. It was identifying these distinct patterns in the data profile which sparked the concept of Levels Classification. Relatively distinct patterns in the distribution of the channel or band levels in one or more bands were associated with each surface feature. Examples of these patterns are shown in Figure 6. Because the line and column graphs indicate the pattern of raw data values across specific earth surface features, they can be used to isolate unique levels ranges of designated earth surface features on a microscale. This is particularly useful when analyzing a complex landscape such as an urban area. It has been found that certain classes, such as water and wetlands, can be extracted easily with these simple graphic processors. However, this technique of analysis is tedious and frequently is not appropriate for preliminary analysis.

C. LINE PRINTER MAPS

The LARSYS Pictureprint function provides a gray scale line printer map or "picture" of the data set. Various methods can be used to produce this graphic display. The staff of ISURSL has found that the use of levels determined through histogram analysis produces an effective density slice map of the data clusters associated with general earth surface classes distinguished in each spectral band. A selected set of line printer character symbols which attempts to represent gray levels easily distinguished by the human eye has been adopted (developed by Dr. William D. Brooks, ISURSL). Geographic patterns of distinguishable classes are displayed by assigning each unimodal spectral range to one of the gray density symbols. In certain cases (i.e. water) simple Pictureprint density slicing of one spectral band is sufficient to produce a thematic map of a class of interest. In general the ISURSL-type Pictureprints are analyzed through traditional photo interpretation techniques. Earth surface features are identified by their shape, associations, and location on the gray scale computer map. These maps also are used to select training areas for Ranger because they identify the location of the most readily distinguishable class patterns in the data set. Figure 4 provides examples of gray scale Pictureprints developed through histogram analysis.

D. BIRTHA

Early in the development of Levels Classification it became apparent the single feature histograms and associated Pictureprints did not provide sufficient information to develop a multidimensional set of spectral levels for intensive classification. Preliminary work was conducted to design a multidimensional histogram processor. At the 1976 LARS Symposium, HINDU, the work of Belur V. Dasarathy was encountered.[3] Dasarathy's work replicated much of the logic which was being developed at ISURSL, thus it was decided to adopt and modify HINDU rather than continue duplicate development.

HINDU" . . . is designed for the purpose of pattern recognition in unsupervised environments through clustering. It is particularly well suited for clustering multidimensional data sets such as those obtained through remote sensing by multispectral scanners."[4] HINDU builds a multidimensional histogram which is used to identify density modes or cluster centers and their boundaries in multidimensional feature space. It is a throughly developed processor with a

Figure 4a. Example of Pictureprints Developed From Ranger for Band 4.

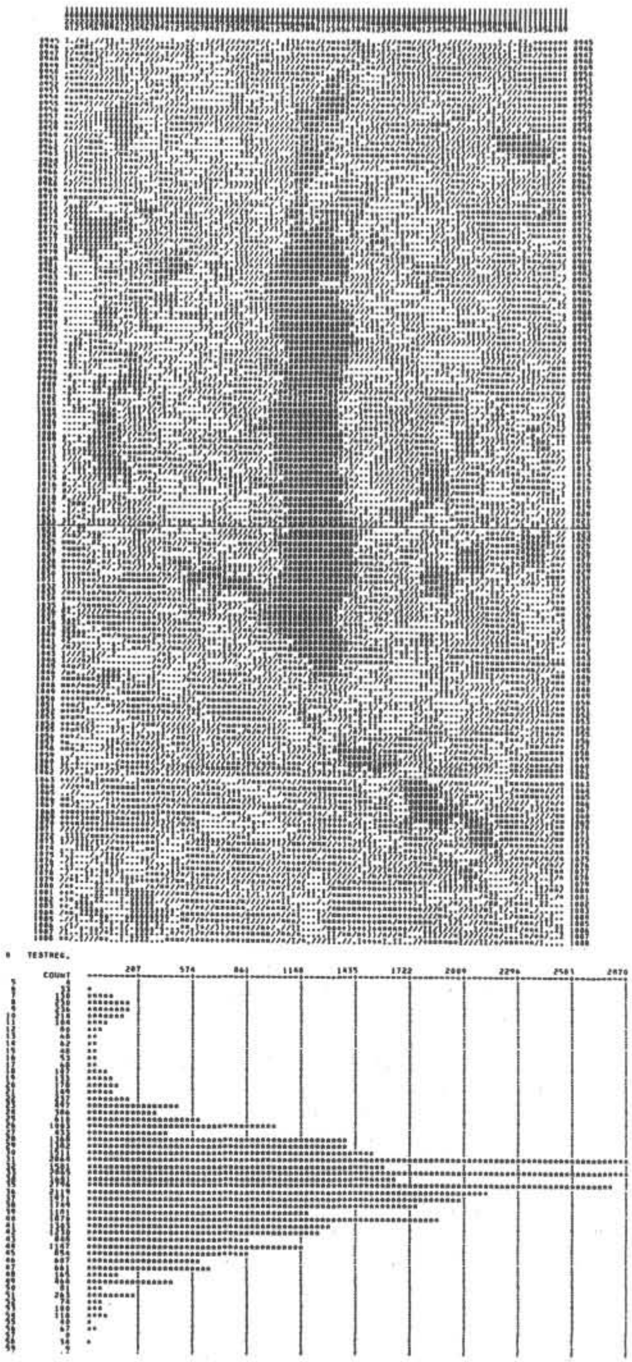

Figure 4b. Example of Pictureprints Developed From Ranger for Band 6.

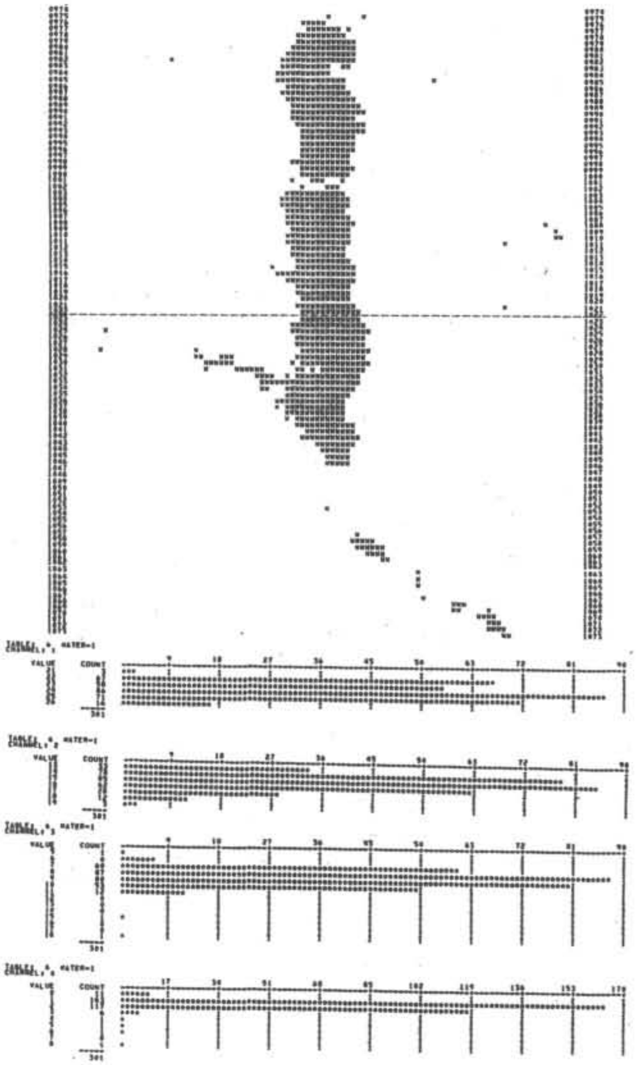

Figure 5. Class Water Developed From Ranger.

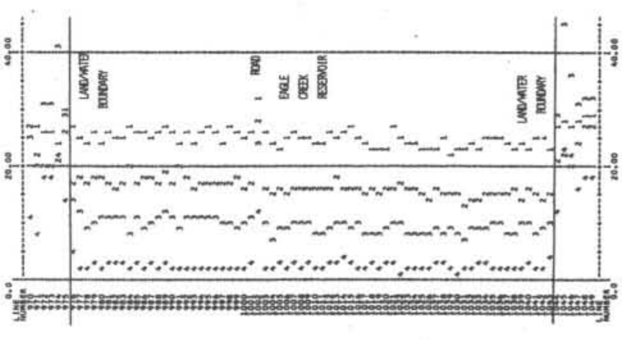

Figure 6. Columngraph Through Center of Eagle Creek Reservoir.

number of optional input and output variables. HINDU can be used independently as an unsupervised classifier; however, to meet the needs of ISURSL it was modified to provide the basic analysis information for Levels Classification.

The ISURSL version of HINDU is designated BIRTHA (Boundary Identification of Ranges Through Histogram Analysis). The basic multidimensional histogram processors were acquired directly from their designer, Belur V. Dasarathy and since have been modified to: 1) make the processors compatible with the LARSYS environment and the Levels Classification approach; 2) reduce core storage requirements; and 3) increase processing speed. (The basic research and modifications performed on HINDU were carried out at the Holcomb Research Institute, Butler University, Indianapolis, Indiana).

BIRTHA analyzes large data sets and constructs a multidimensional histogram. The terrain of the histogram contains every significant peak and valley in the feature space. Boundary locations in the terrain are identified. The decision process by which the boundary is located in the terrain is flexible due to the inclusion of several optional analytic techniques. These techniques include the following generally accepted decision methods:

1. Closest Cluster Centroid
2. Nearest Neighbor
3. Maximum Likelihood
4. Discriminant Hyperplane
5. Committee Approach of 2, 3, and 4
6. Voter Approach, all of the above except 1.

Experience has shown that no statistical technique always is accurate in assigning cluster boundaries. Interaction between analyst and machine is necessary to guide proper cluster boundary location. BIRTHA generates a histogram graphic of the reflectance density distribution in each spectral band for each cluster class identified. These graphics provide the analyst a detailed indication of the substructure in each cluster and the boundary locations which have been selected between cluster classes. This information allows the analyst to adjust the levels boundaries and investigate the potential of identifying subclasses within the general cluster classes.

One of the most significant advantages of BIRTHA is the large data samples from the data set can be clustered (Figures 7 and 8). This provides a close approximation of the cluster class structure throughout the data set and avoids the traditional problem of selecting small but "representative" training areas in the data set. Cluster classes are less inferential and more descriptive when large sectors of the data population are subjected to cluster analysis. Large area clustering has previously been impractical due to the high computer time demands inherent in using traditional cluster techniques. Computation time is minimal using HINDU and BIRTHA. For example, Dasarathy generated seven clusters in a 500 line by 500 column (250,000 pixels) sector of a LANDSAT frame which accurately identified forest, agriculture, pasture, water, urban (residential), urban (non-residential) and pasture/forest in 89 CPU seconds on an IBM 360/65. CPU time increases slightly with the generation of each additional cluster.

E. POTENTIATOR

One of the most novel aspects of the Levels Classification approach is that only those spectral bands which discriminate each class must be specified. However, once an analyst has developed multidimensional levels ranges for each class of interest it is often difficult to manually integrate the information to derive the optimum classification scheme. The Potentiator is designed to simultaneously examine all class levels ranges and: 1) minimize the number of channels or spectral bands needed to separate each class from all other classes; 2) indicate where minimum overlap occurs and compute a new boundary for classes which are not separated; 3) compute the unused feature space or the null class; and 4) estimate the probability of each class occurance in the data set and order the classification sequence.

All pairwise class combinations are tested to minimize the number of channels required to discriminate a single class. The spectral bands which separate the classes are noted. Where two classes are not separated by any of the spectral bands, the band where minimum overlap occurs is noted and a new boundary between the classes is computed. Once all class discriminant features are finalized the unused feature space is computed to identify the null class. The probability of class occurance in the data set is computed by compiling a histogram from one or more samples of the data population. The percentage of the data population expected to be in each class is the

Figure 7a. Cluster Map Generated by BIRTHA.

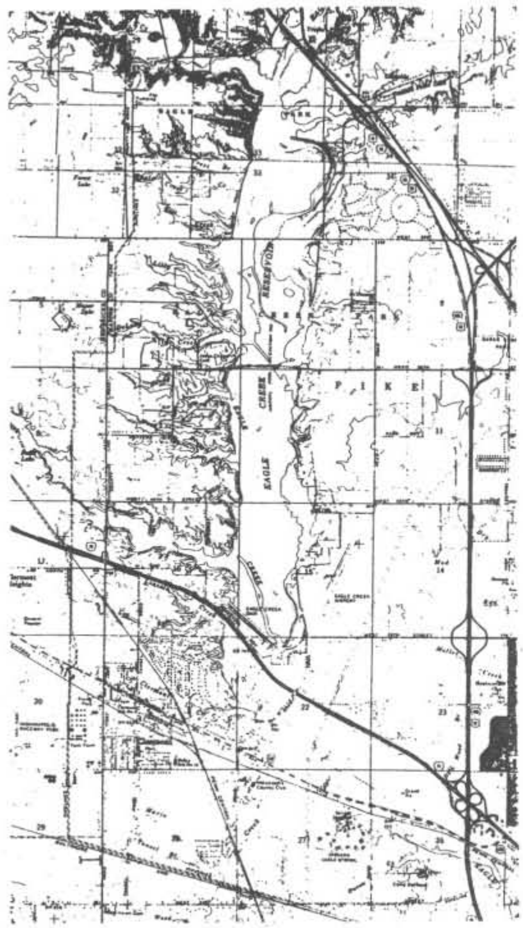

Figure 7b. USGS 7.5 Minute Quadrangle Windowing Eagle Creek

levels range of each class. The classification scheme is then ordered from highest to lowest class probability.

The Potentiator provides the most efficient classification scheme which maximizes the discriminant power of the classes while minimizing the computuational time required to generate the final classification results. This processor currently is undergoing final development and programming and soon will be available in the ISURSL Levels Classification system.

Figure 8. BIRTHA Map Showing Two Classes of Water.

F. PRINTRESULTS

The LARSYS Printresults function is used to generate the final classification maps. There are several optional forms in which classification results can be displayed. A computer tape can be produced which can be integrated into a computer based information system. Line printer gray scale maps can be generated or image display color and black and white photographs produced. Selected aspects of the Printresults function have been altered to allow subareas of a classification study to be displayed in an efficient manner. Figure 9 is an example of a Levels Classification Printresults gray scale printer map.

VII. APPLICATIONS OF THE ISURSL LEVELS CLASSIFICATION SYSTEM

The Levels Classification approach has been used for earth surface feature classification in five projects of which four were funded by state and federal agencies. In total approximately 140,000 sq. km. of land and water features have analyzed using Levels Classification techniques on LANDSAT -1 and LANDSAT-2 multispectral data. All five projects were completed successfully with classification accuracy comparable to that obtained through more traditional methods of machine processing of multispectral data. The earth surface feature information developed for the five contract research projects currently are being considered to make regional land use planning decisions, estimate water quality, and provide baseline forest type distribution information. Final user evaluation of the classification results are not available yet, but preliminary comments from users who have had access to the land cover information developed by the ISURSL are favorable overall. Table 1 summarizes pertinent information and categories of earth surface features which were developed for ISURSL projects that used the Levels Classification approach.

VIII. CONCLUSIONS

The Levels Classification approach to machine processing of multispectral data has proven cost effective in each basic and applied research project conducted at ISURSL. However the Levels Classification system still requires further sophistication which only can be acquired through diverse and rigorous research. Development, refinement, and testing of the Levels Classification system by analysts with a variety of interests and application needs are required to

Table 1. Summary of ISURSL Applied and Basic Research using Levels Classification

A.	Project	Land cover inventory of Indiana	
	Funding Agency --------	State Planning Services Agency (SPSA)	
	Funding Level ---------	Less than $.40/sq. km.	
	Data Used -------------	Nine LANDSAT frames (June 8-11, 1973), geometrically corrected	
	Area Classified -------	State of Indiana, 93,729 sq. km.	
	Display Format --------	1:24,000 scale computer maps with statistical summary of classes	
	Project Objectives ----	Develop baseline land cover data for Indiana	
	Classes Developed -----		
	Forest	Immature Cropland	Older Residential, Single Home
	Water	Bare Soil/Spoil	Dense Residential
	Mature Cropland/Pasture	Wetlands	Commercial/Industrial
	Moderately Mature Cropland	Large Lot Suburban	Cloud and Shadow
B.	Project	Land use inventory of planning region 6 (Indiana)	
	Funding Agency --------	EPA/WCIEDD (Region 6 planning agency)	
	Funding Level ---------	Approximately $.95/sq. km.	
	Data Used -------------	Three LANDSAT frames (4/75, 7/75, 9/75) geometrically corrected	
	Area Classified -------	Six Indiana counties - 6,300 sq. km.	
	Display Format --------	1:24,000 and 1:72,000 scale computer maps with statistical summary	
	Project Objectives ----	Land use information to estimate water pollution potential by watershed	
	Classes Developed -----		
	Water, Low Sediment	Open Forest	Bare Soil/Spoil
	Water, Moderate Sediment	Pasture	Older Residential
	Water, High Sediment	Row Crop	Commercial/Industrial
	Dense Forest	Small Grain	Suburban
C.	Project	Distribution of forest in Central Ohio	
	Funding Agency --------	U. S. Forest Service	
	Funding Level ---------	Less than $.30/sq. km.	
	Data Used -------------	Three LANDSAT frames, geometrically corrected	
	Area Classified -------	Scioto Valley Watershed, Ohio, 22,000 sq./km.	
	Display Format --------	1:24,000 scale computer map, statistical summaries, CCT	
	Project Objectives ----	Acquire baseline information of forest in central Ohio	
	Classes Developed -----	Four Classes of Forest	
D.	Project	Ecological zone mapping in coastal areas	
	Funding Agency --------	Indiana State University	
	Funding Level ---------	Approximately $.40/sq. km.	
	Data Used -------------	One LANDSAT tape (October, 1972), not geometrically corrected	
	Area Classified -------	Southeastern North Carolina, 2,000 sq. km.	
	Display Format --------	1:24,000 scale computer maps and color coded digital imagery	
	Project Objectives ----	Identify ecological zones for coastal zone management research	
	Classes Developed -----		
	Ocean, < 1 meter	Sand with Dense Grass/Shrub	Hydrophytic Forest 1
	Estuary	Dense Maritime Forest	Hydrophytic Forest 2
	Shallow Water, > 1 meter	Pine Forest	Tall Marsh Grass
	Sand	Shadow	Short Marsh Grass
	Sand with Sparse Grass	Dense Grass in Muck (non marsh)	Cloud
E.	Project	Land use classification of planning region eight (8 Indiana counties)	
	Funding Agency --------	Holcomb Research Institute, Butler University, Indianapolis, Ind.	
	Funding Level ---------	$.60/sq. km.	
	Data Used -------------	LANDSAT (9-30-72) geometrically corrected	
	Area Classified -------	9,749 sq. km.	
	Display Format --------	1:24,000 scale computer maps (full classification for each county)	
	Project Objectives ----	To inventory crop types, forest cover and major urban features	
	Classes -----		
	Res*	Central Business District	Residential Grassy
	River 1	Residential 1	Residential
	Bare soil	New Residential	Test 2
	Forest	Grassy	Clouds
	Urban Transportation 1	Agriculture	Shadow
	Urban Transportation 2	Agriculture 2	Other

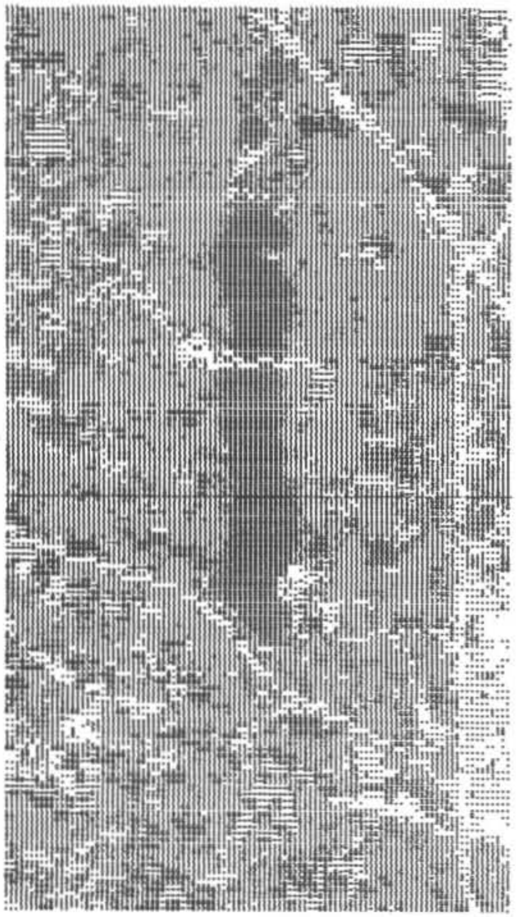

Figure 9a. A Levels Classifications Study of the Eagle Creek Reservoir Region.

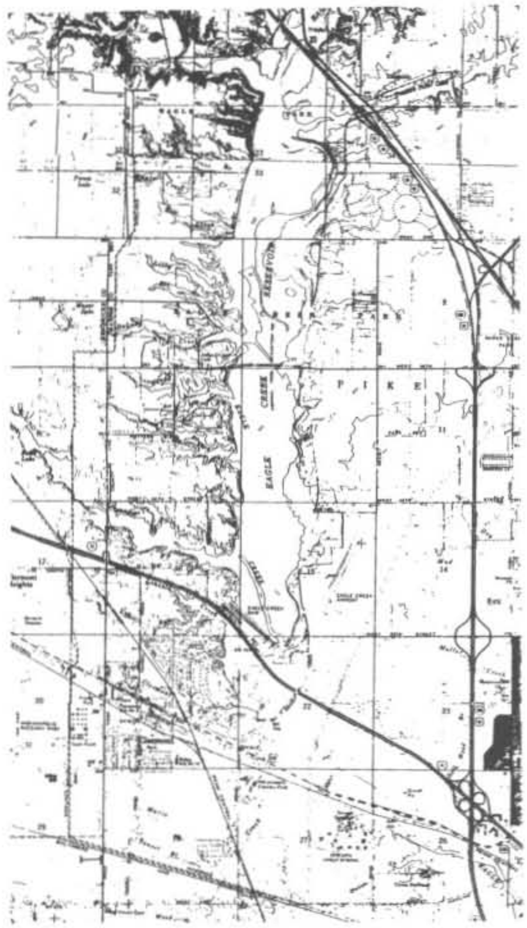

Figure 9b. USGS 7.5 minute Quadrangle windowing Eagle Creek Reservoir Area.

fully realize the potential of this low-cost technique for machine processing of multispectral data. Continued modification of old ideas, development of new concepts, and open acceptance of outside ideas, and criticism has been fundamental to the successful implementation of the Levels Classification concept. Continued successful evolution of the Levels Classification approach will be a function of the scientific objectivity and creativity of individuals engaged in this research.

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ACKNOWLEDGEMENTS

The authors wish to thank Norman Cooprider and Michael Talbett for their assistance in photography and cartography. The authors also gratefully acknowledge the assistance of ISURSL research associates Stephen Stadler, Len Alger, Van Maness, and Gary Westerman who have helped in testing the Levels Classification approach. The technical support provided by LARS/Purdue was invaluable in implementing ISURSL programs into LARSYS.

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